Enhancing Cluster Science with LSST and External Data Sets[1]

[1]Not a cross-correlation talk![2]

[2]as such

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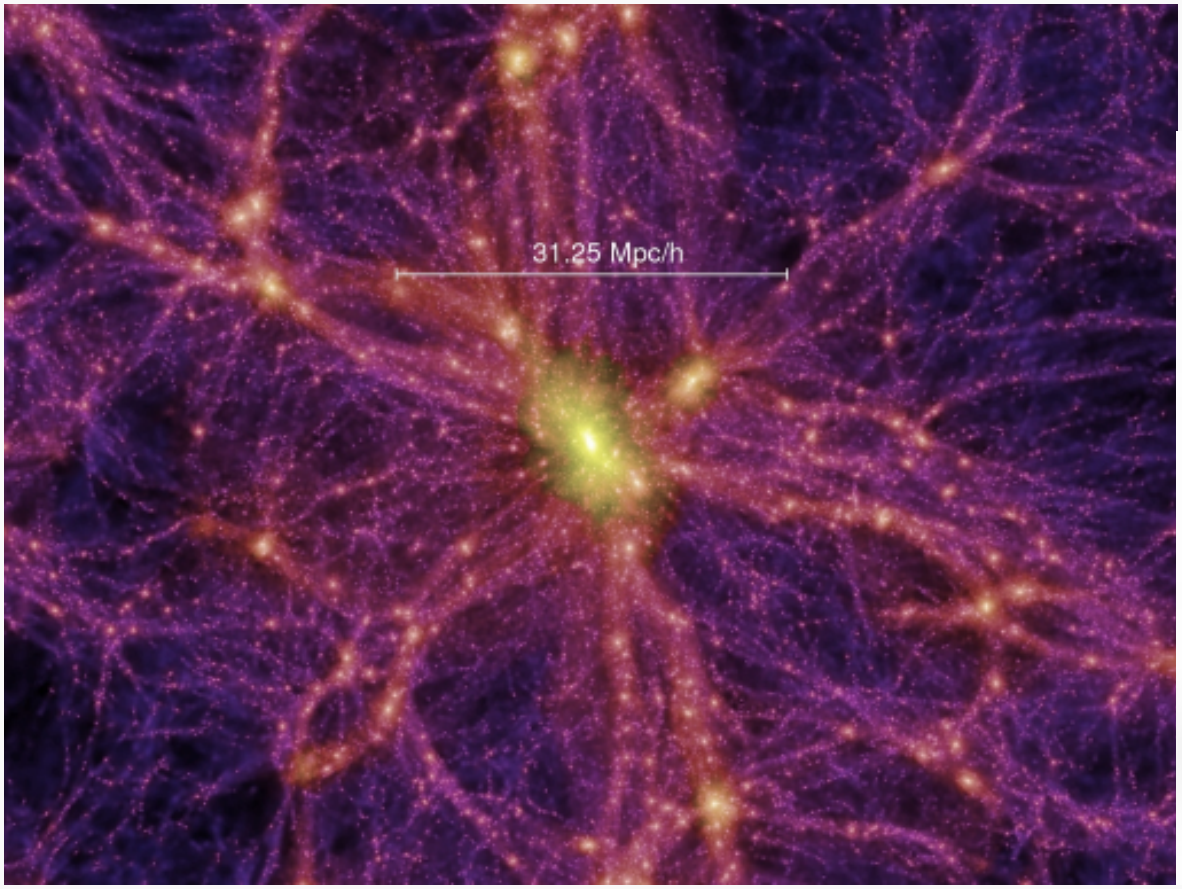
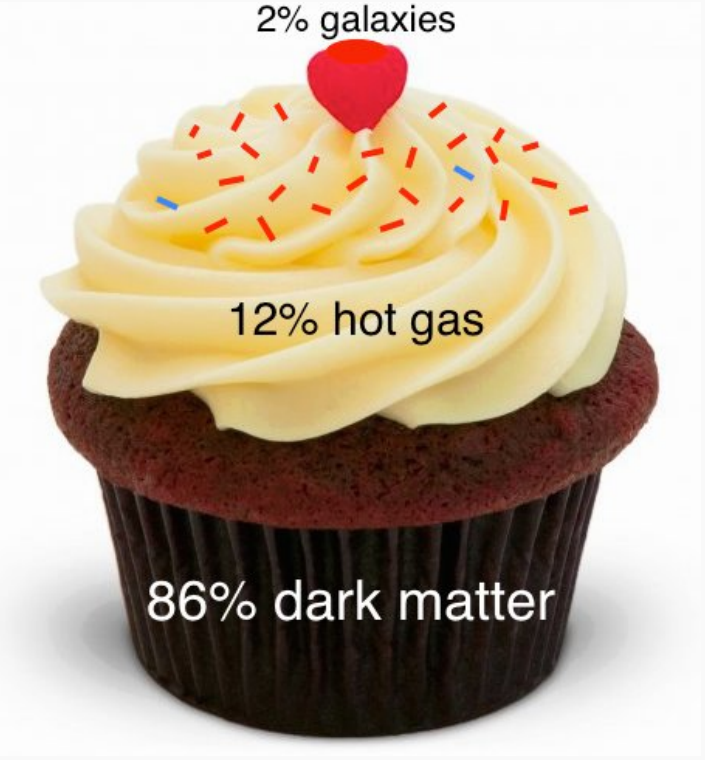
Cross-correlation Spectacular with LSST: Exploring Synergies Between LSST and External Datasets to Discover Fundamental Physics

May 24, 2016

Unnecessary introduction

Galaxy cluster: a very massive, bound collection of dark matter, ionized gas, and galaxies ($M \gtrsim 10^{14}\, M_\odot$, $kT \gtrsim 1\,\mathrm{keV}$).





Cluster cosmology

- Mass function $\leftarrow$ growth of structure, expansion, neutrino mass
- Gas-mass fractions (standard quantity) $\leftarrow$ cosmic expansion and $\Omega_{\rm m}$
- Clustering of clusters $\leftarrow$ growth of structure, expansion
- X-ray and mm pressure measurements $\leftarrow$ cosmic expansion
- Bulk flows $\leftarrow$ growth of structure, expansion
- Merger statistics $\leftarrow$ dark matter cross section
- Internal structure $\leftarrow$ dark matter, gravity
- ...

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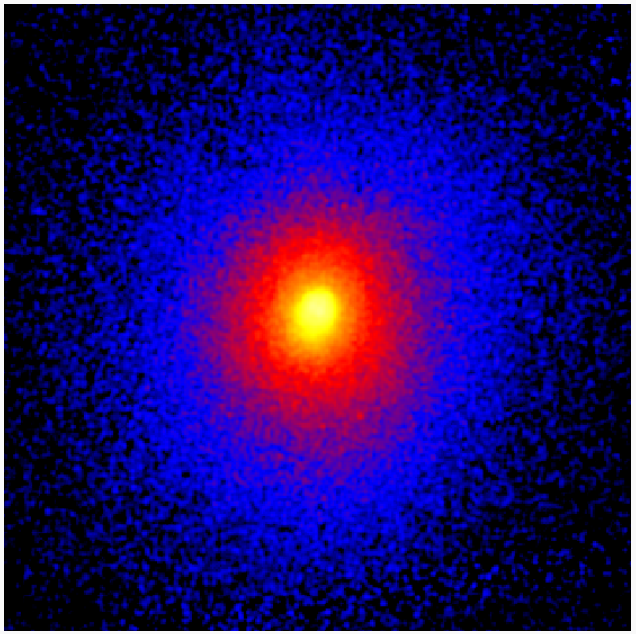
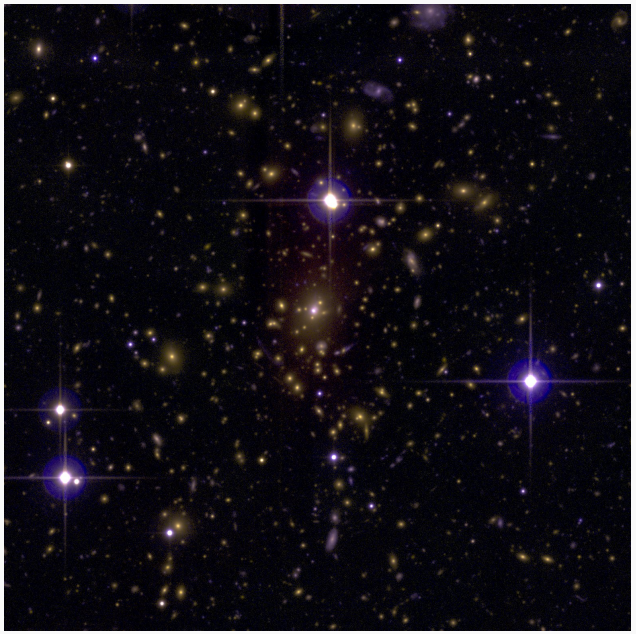
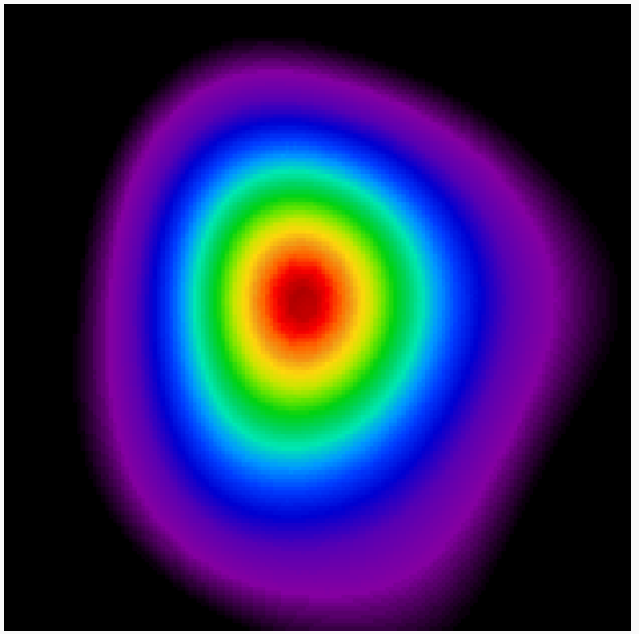
Cluster surveys

Three main survey strategies (increasing wavelength order):

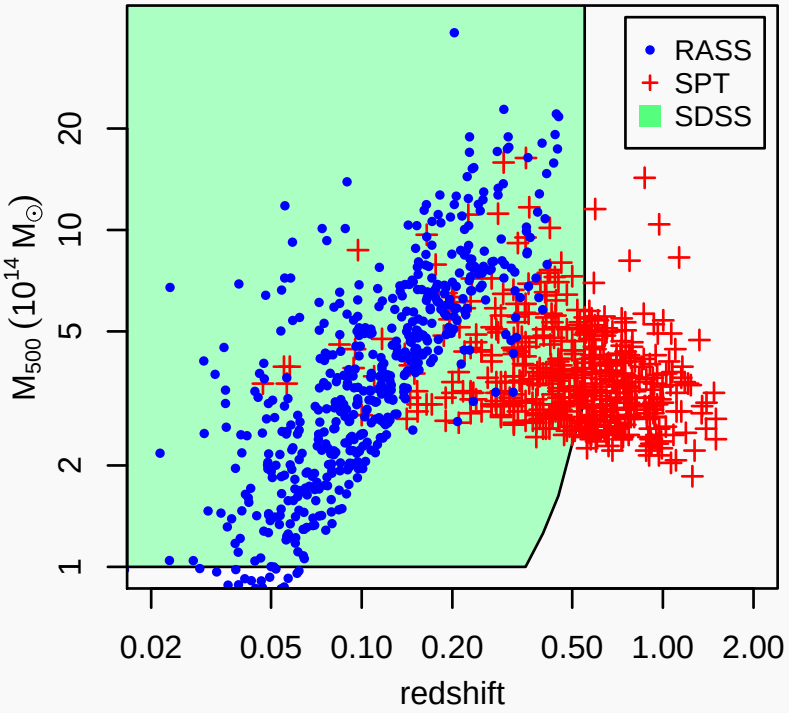
- X-ray: emission from hot intracluster medium (ICM)
- optical/IR: cluster galaxies and lensed background galaxies
- mm: SZ effect (CMB spectral distortion) due to ICM

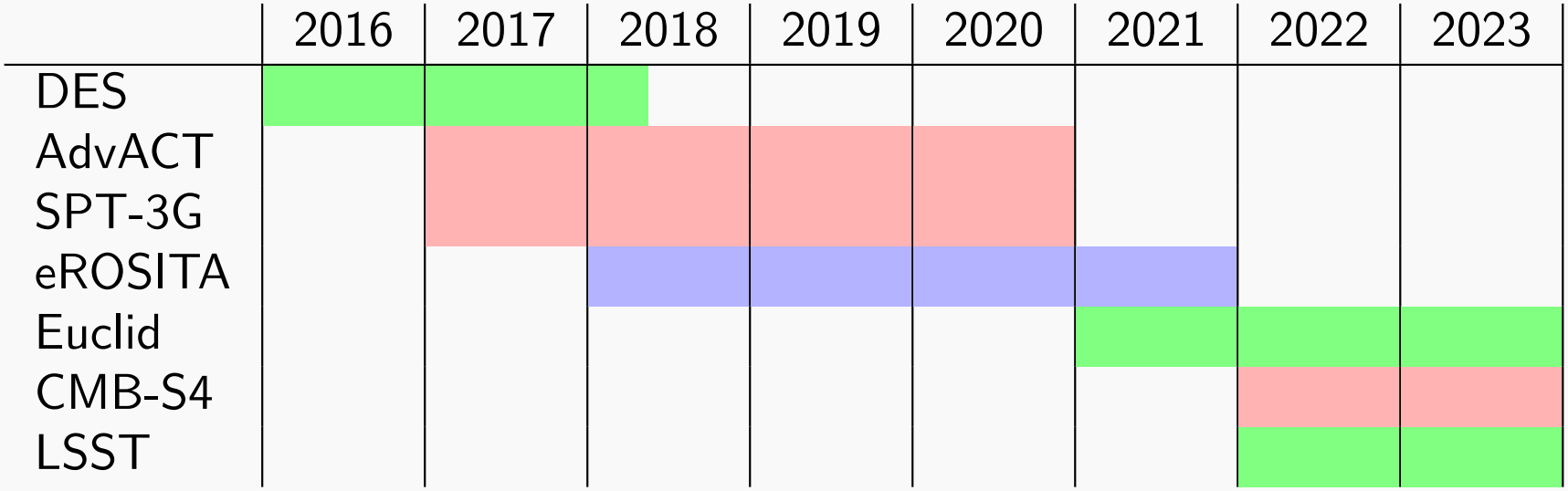
Cluster surveys

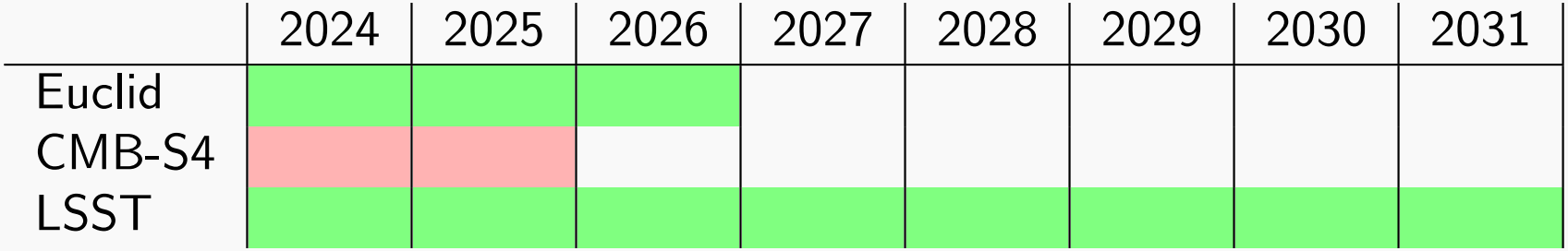
Three main survey strategies (increasing wavelength order):

- X-ray: emission from hot intracluster medium (ICM)
  $\rightarrow$ Most massive clusters to high z, groups at lower z
- optical/IR: cluster galaxies and lensed background galaxies
  $\rightarrow$ High completeness to low masses
- mm: SZ effect (CMB spectral distortion) due to ICM
  $\rightarrow$ Massive clusters at any redshift



Current/future large surveys





Current/future large surveys

1. In 10 yr, we will have a much more comprehensive view of clusters in the Universe.
2. LSST is not (by itself) the ultimate cluster survey.

Needs

1. Predicted halo mass function from simulations
2. Observed number of clusters as a function of z and survey signal
3. Stochastic relation between mass and observable signal(s)

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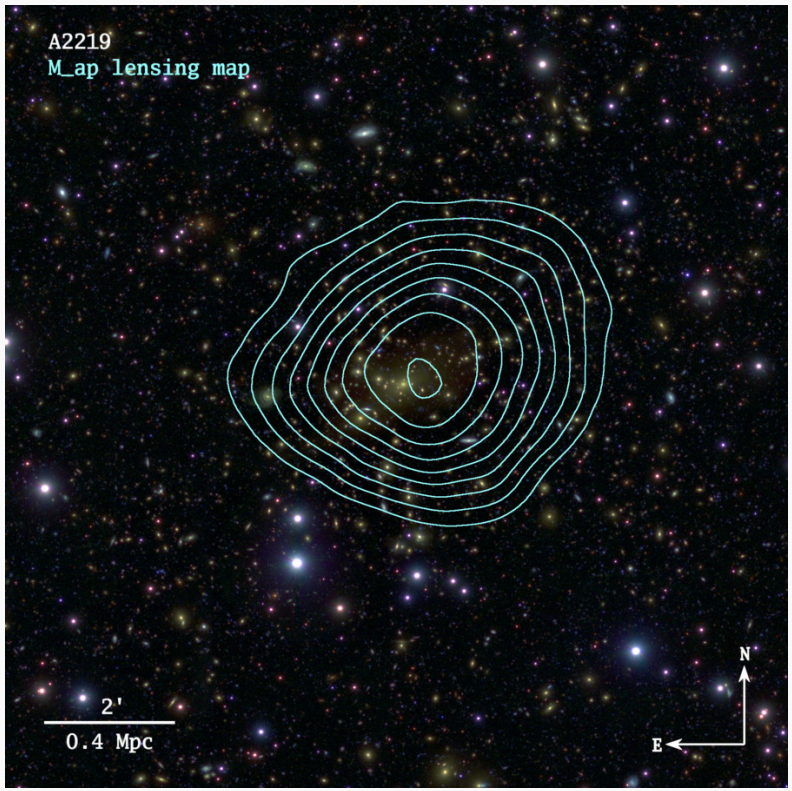
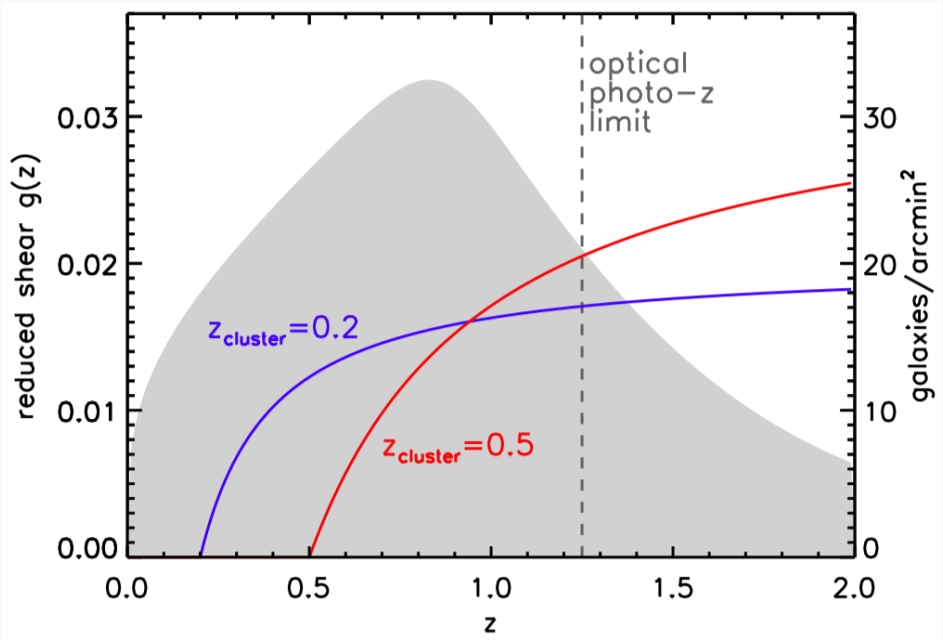
Optical surveys like LSST can provide several of these.

Current status

Accurate (absolute) masses: galaxy-cluster weak lensing

- Unbiased with good data, careful analysis, accurate centers
- Progressively harder at higher cluster z – current methods can probably be pushed to $z \sim 0.9$
  (from the ground – space would be nice)



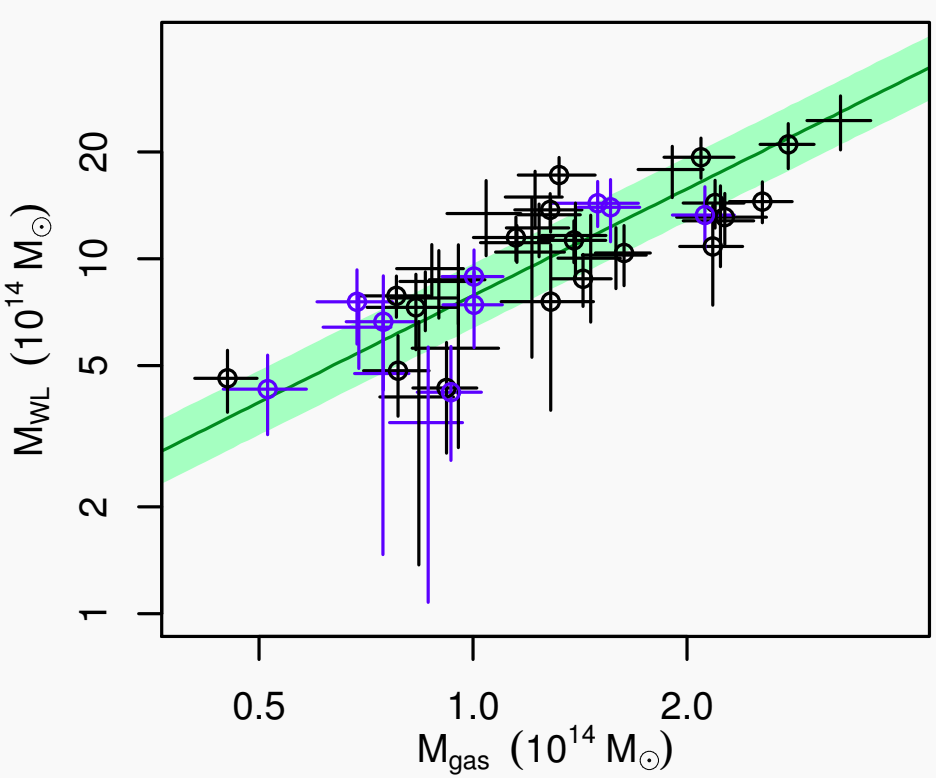


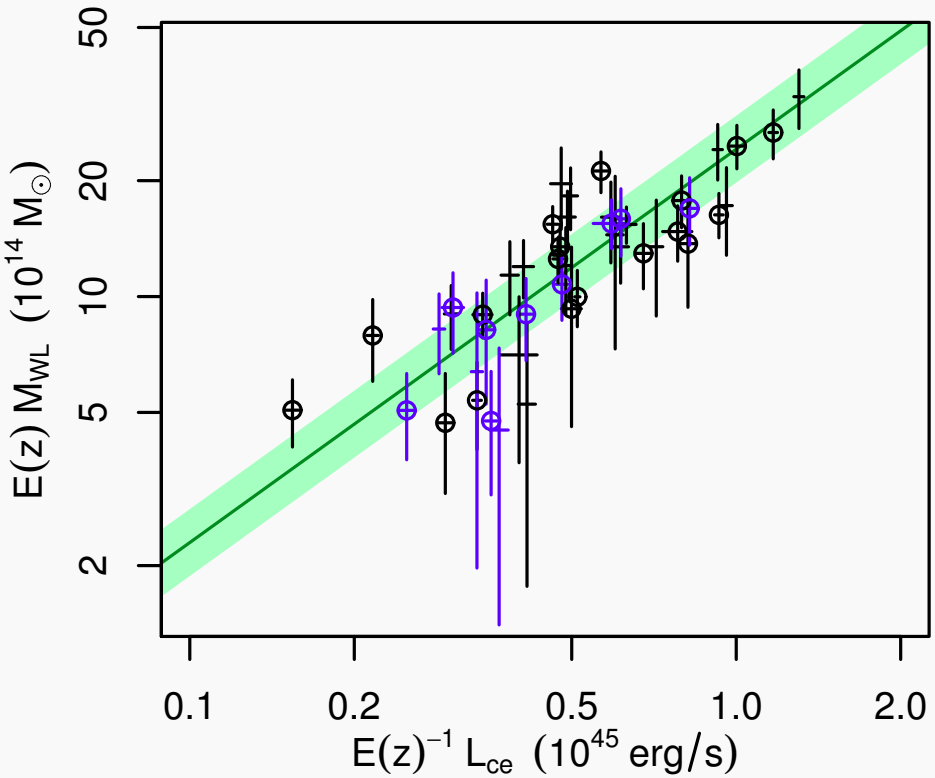
From "Weighing the Giants"

Current status

Precise (relative) masses: X-ray proxies

- Center-excised luminosity, gas mass, temperature, $Y_{\rm X}$...
- Intrinsic scatters $\lesssim 15\%$, requiring ~ 100–1000's of counts





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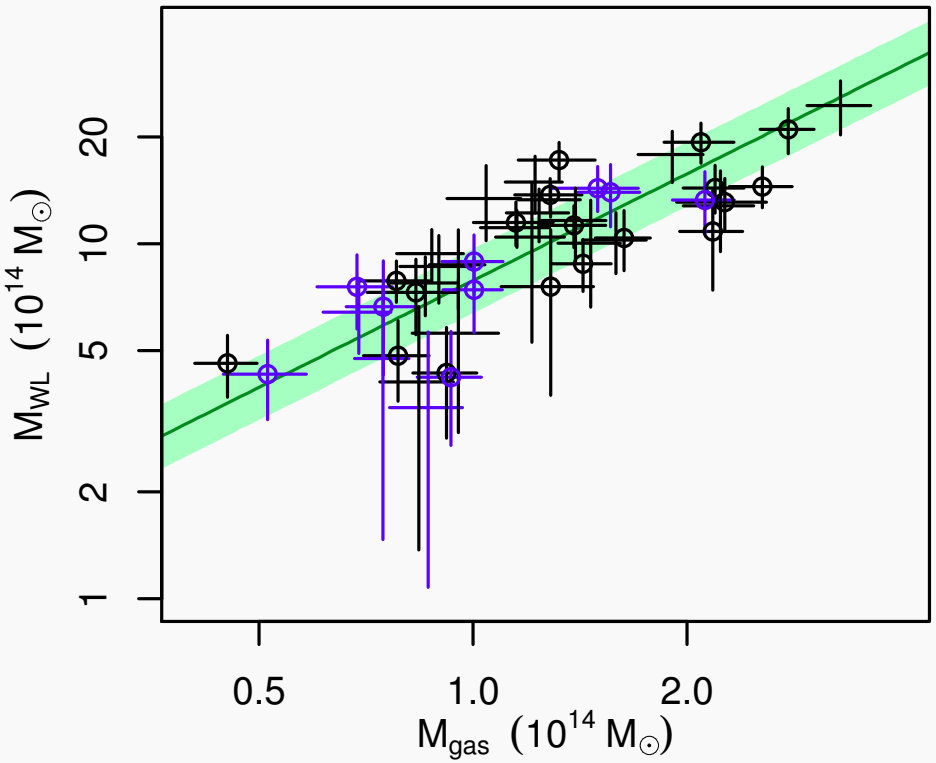

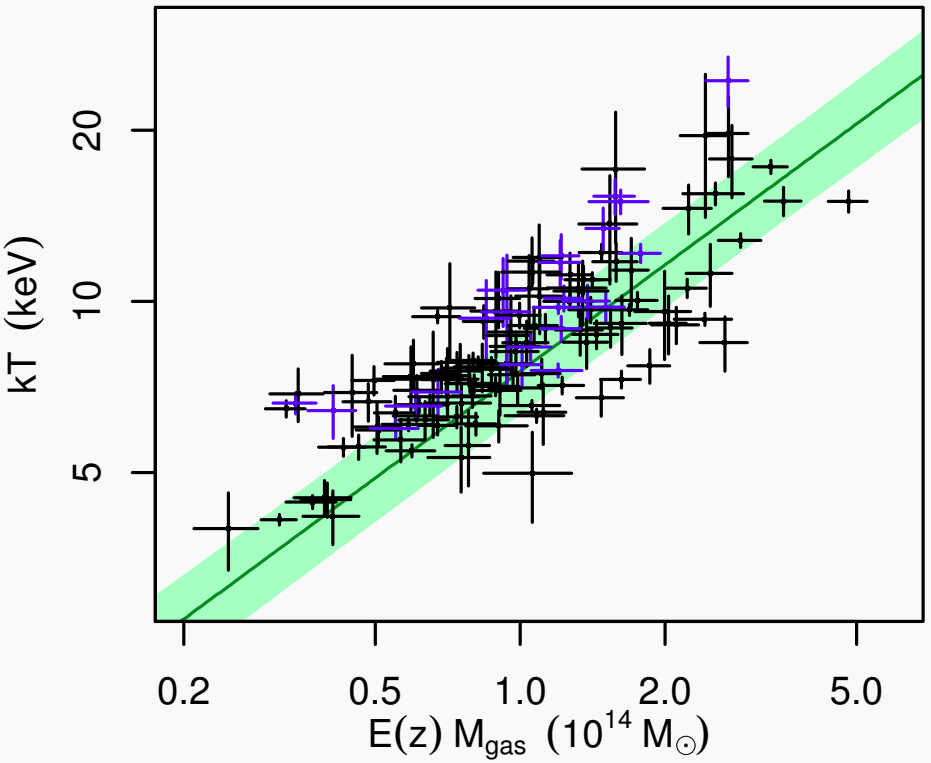

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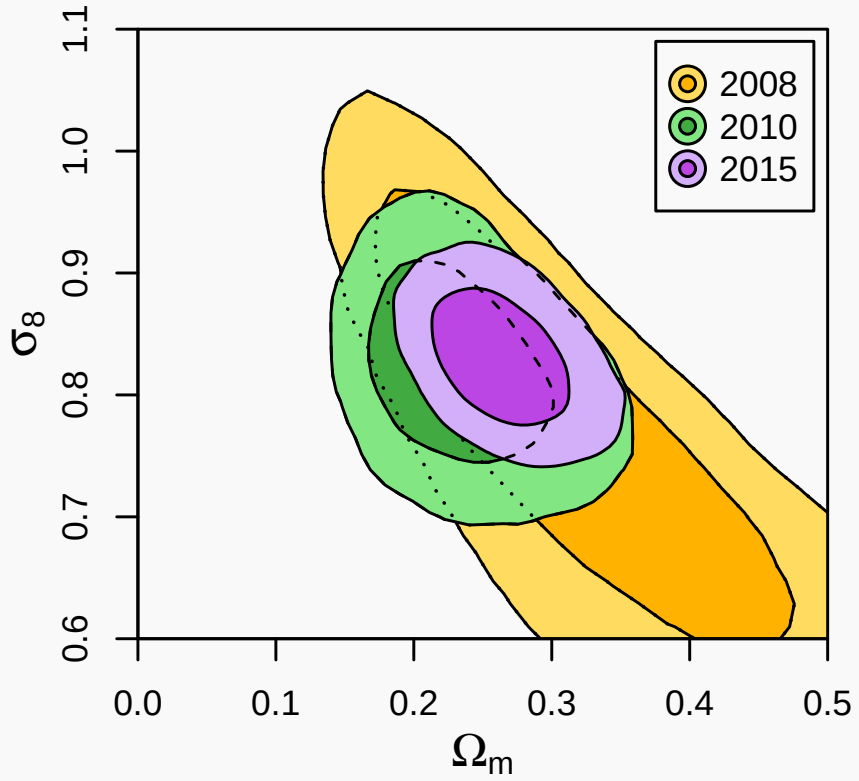
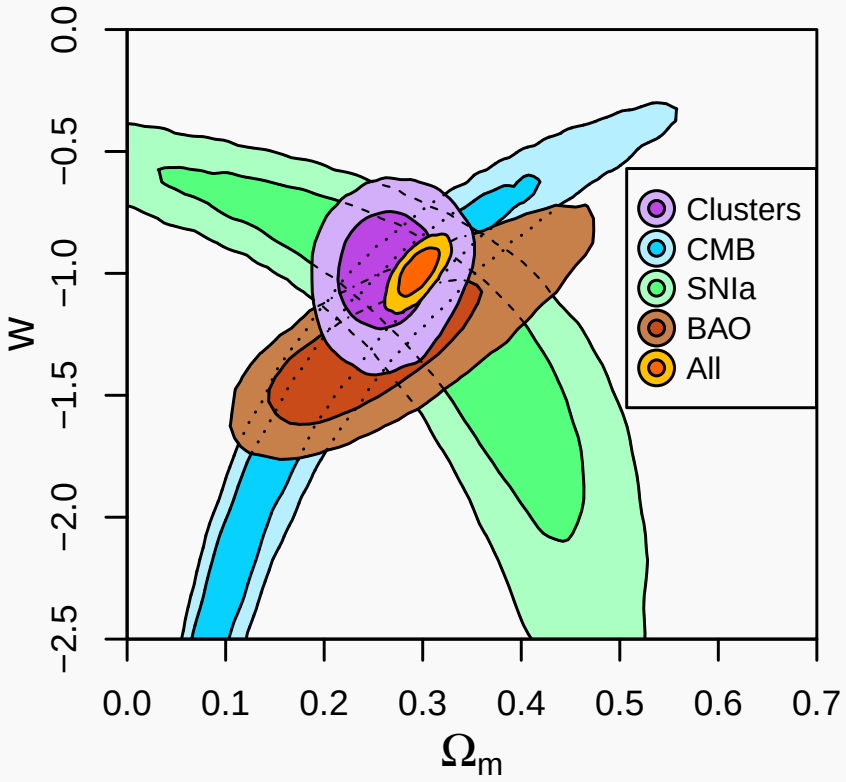


- Improvement has been rapid
- Significant gains to be had from both improving absolute mass calibration (accuracy) and obtaining precise relative masses (precision).

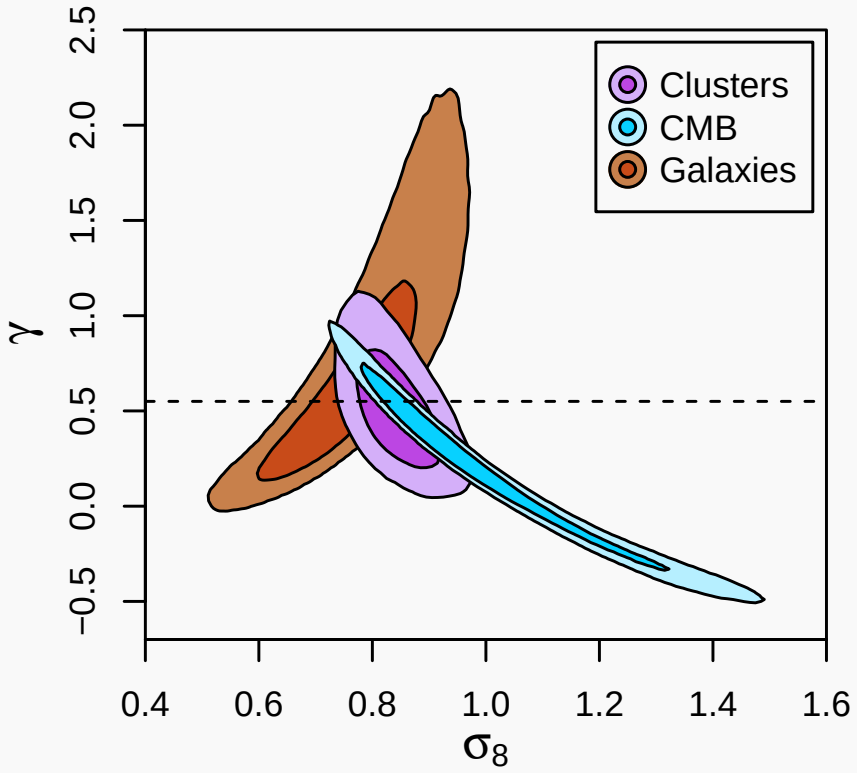
From "Weighing the Giants"

Current status

constant-w models



growth index (modified gravity) models



Clusters alone:

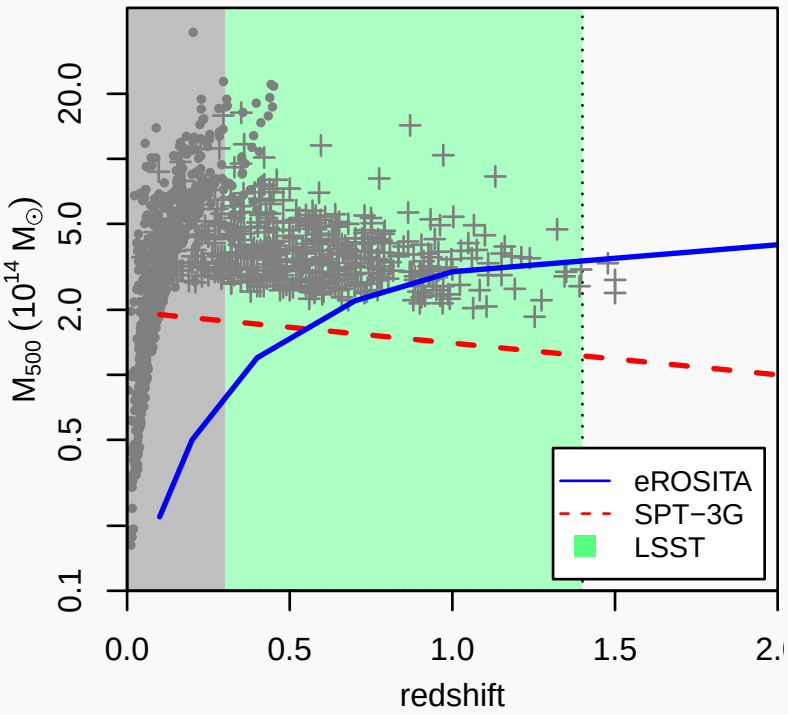
$$\Omega_m = 0.261 \pm 0.031$$
$$\sigma_8 = 0.831 \pm 0.036$$
$$w = -0.98 \pm 0.15$$

Clusters alone:

$$\Omega_m = 0.257 \pm 0.030$$
$$\sigma_8 = 0.833 \pm 0.048$$
$$\gamma - 0.55 = -0.07 \pm 0.19$$

From "Weighing the Giants"

Where would new projects have an impact?



- Spectroscopy to improve photo-z's
- High-z confirmation and photo-z's
- High-z absolute mass calibration
- Relative mass proxies at high-z and low mass

Spectroscopy

- Photo-z training sets for faint galaxies behind and in clusters
- Impacts cluster finding and (especially) mass calibration

Need continuing access to ground- and space-based facilities, plus future projects like DESI, HSC-PFS, WFIRST, etc.

Confirmation/photometry

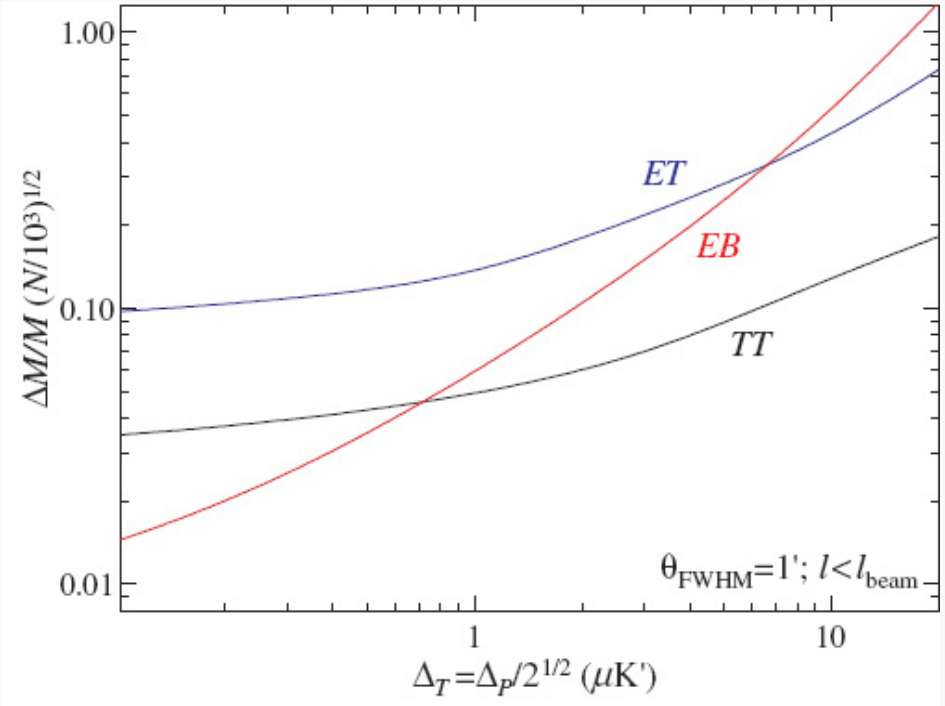
- Confirmation and photo-z's at high redshifts
- Galaxy-cluster lensing (absolute masses) at high redshifts?

Need continuing access to large ground-based and space-based facilities (e.g. VLT, Magellan, Keck, TMT/GMT, WFIRST, . . .)

Absolute masses at $z \gtrsim 1$

Not yet clear what the best strategy will be yet...

- Push galaxy-cluster lensing to the limit?
- Self-calibrate using cluster clustering?
- Velocity dispersions (lots of spectra)?
- CMB-cluster weak lensing – potential synergy with CMB-S4



Hu$^+$ 2007

Relative mass proxies

- Key probe of survey observable–mass relation, evolution & scatter
- Also constrains mis-centering/projection systematics (lensing and optical cluster-finding)
- X-ray/SZ surveys will provide *some* information for free

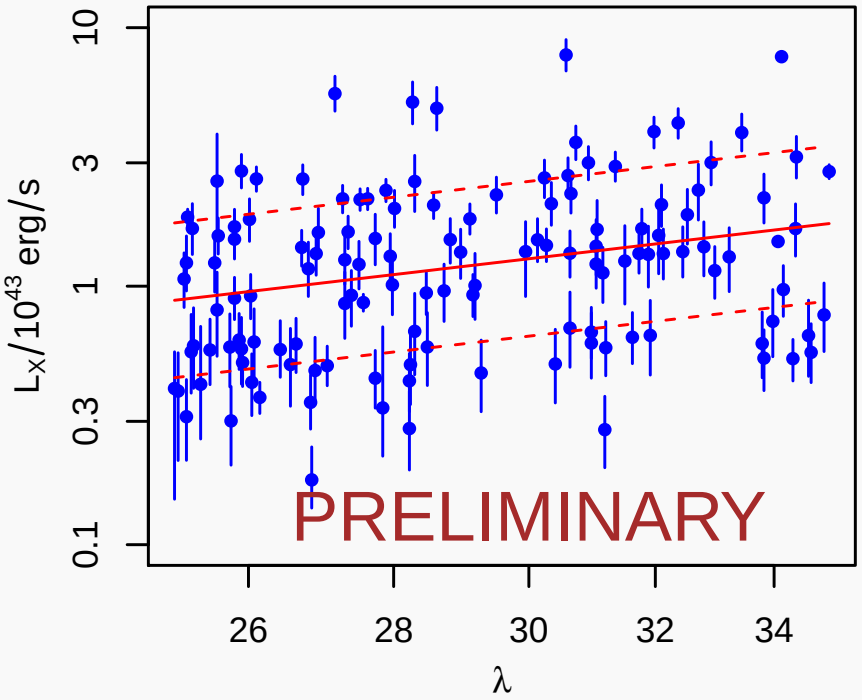
X-ray facilities:

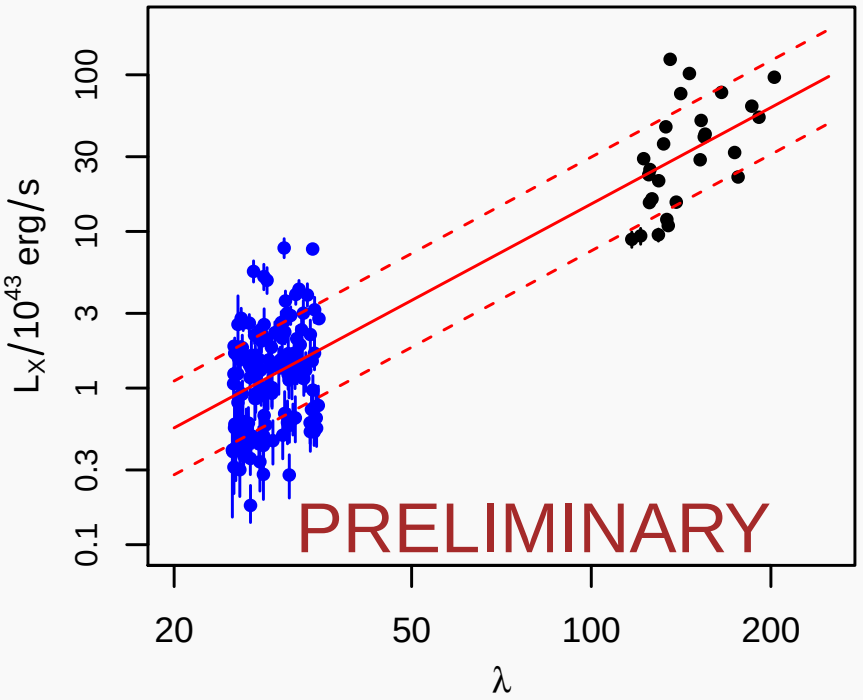
	launch	area/Chandra	HEW
Chandra	1999	1	$1''$
XMM	1999	4	$16''$
eROSITA (survey)	2018	16	$28''$
eROSITA (pointed)	...	...	$16''$
ATHENA	2028	50	$5''$
X-ray Surveyor	$\gtrsim 2030$?	50	$< 1''$

Current events: calibrating optical richness

Approach 1: Complete X-ray follow-up of richness-selected clusters

- Includes 1st large ($N \sim 150$) sample of typical-λ clusters
- Constrains scaling, scatter of λ, and centering/projection, as a function of mass



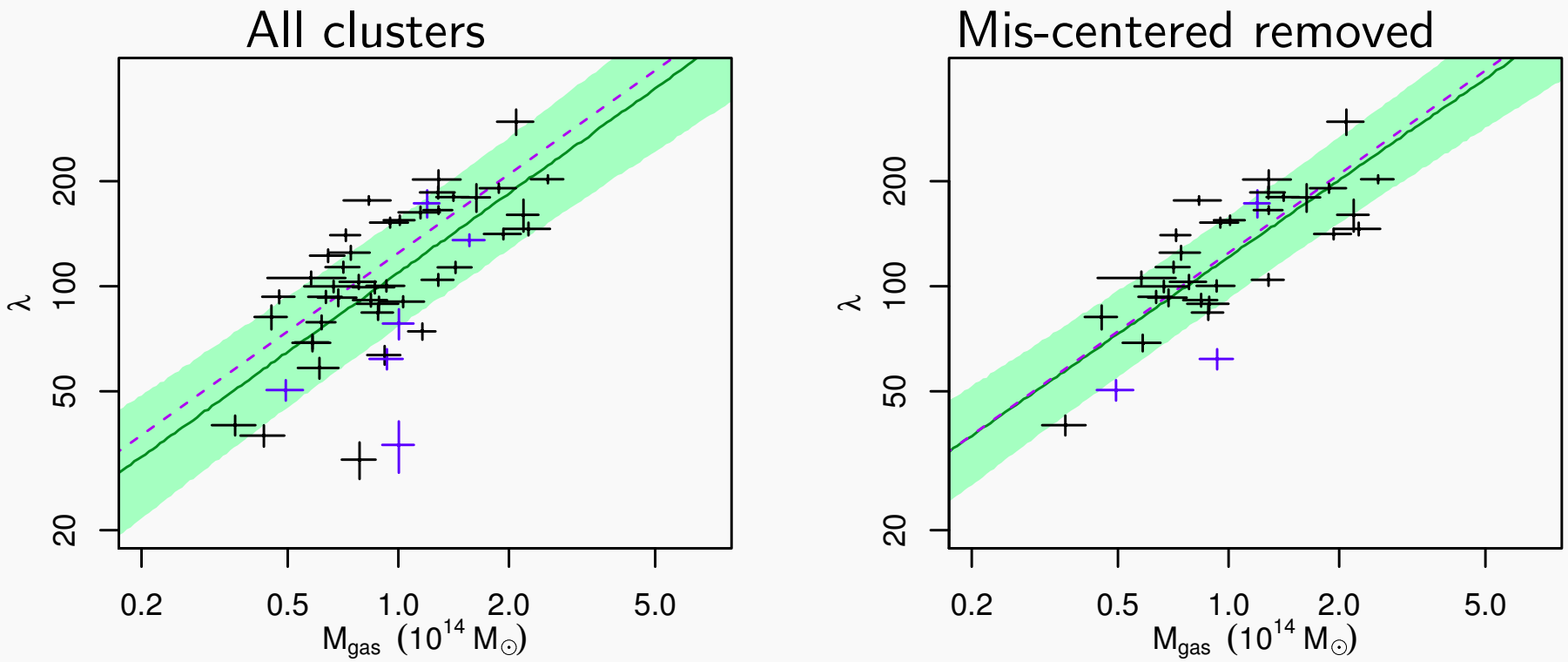


von der Linden^{+} in prep.

Current events: calibrating optical richness

Approach 2: Richness scaling of massive, X-ray selected clusters

- Non-λ selection, but richer information per cluster



Purple line = Simet et al. (stacked lensing)

AM$^+$ in prep.

Summary

- By the 10 yr LSST era, our map of clusters in the Universe will be pretty comprehensive.
- Targeted investment in supporting observations can significantly enhance the science return of these new cluster catalogs.
- Much of what we'd like to do is very straightforward, but there are also some exciting new avenues. There are places where new data clearly benefits multiple probes/projects (e.g. spectroscopy, CMB).